Operational Evaluation of the Direct-To Controller Tool

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Abstract

Direct-To is a decision support tool for en route radar controllers that provides clearance advisories for wind-favorable direct routes and information on potential traffic conflicts. Direct-To includes a highly automated "what-if" trial planning function that allows controllers to quickly visualize, evaluate, and input flight plan amendments for route and altitude changes. Direct-To continuously analyzes all aircraft for wind-favorable direct routing opportunities and for traffic conflicts. "Direct-To" route advisories and conflict information are displayed in the flight data block and in optional lists on the controller's traffic display. A mouse (or track-ball, hereafter referred to as "mouse") click on a conflict advisory, either in the flight data block or the Conflict List, toggles a graphic display of conflict information. A mouse click on the data block activates the trial planning function which shows a graphic display of the trial route, and analyzes the route for traffic conflicts, preferential routing restrictions, and flying time. The trial planner allows the controller to quickly select a different fix and/or add an auxiliary waypoint, by a point and click action. A final mouse click sends the flight plan amendment to the Host computer. An operational evaluation of the Direct-To Tool was conducted at Fort Worth Center from May 21 – June 14, 2001. Direct-To functionality was implemented by connecting one additional software module to the daily use CTAS Traffic Management Advisor system at Fort Worth Center. The user interface was deployed on flat panel auxiliary displays at 3 high altitude sectors. Over a four week period controllers activated 3204 trial plans and sent 1198 Direct-To flight plan amendments to the Center Host computer during 136 sector-hours of operation. On average, one trial plan was created every 2.5 minutes, and one Direct-To Host amendment sent every 7 minutes. Controller feedback on the Direct-To Tool was consistently very positive and the controller team felt that all Direct-To functionality would be beneficial if integrated into their R-Side traffic situation displays. Controllers used Direct-To during a wide variety of traffic conditions including very busy (Monitor Alert) periods. During severe weather periods, Direct-To identified aircraft on obsolete weather avoidance routes resulting in an average savings of 9.4 minutes per flight. A methodology is presented to estimate the net flying time savings that could be achieved with Direct-To aiding compared to baseline (no tool) operations. Test data show a net savings of about 1 minute for some flights and suggest a net operational savings of 900 flying minutes per day or $9,000,000 per year.

Introduction

NASA and the FAA are developing automation tools for air traffic controllers that will enable reduced restrictions and improved efficiency in the National Airspace System. The Direct-To Tool is part of the Center/ TRACON Automation System (CTAS) and is an extension of the Conflict Probe, Trial Planner (CPTP) functionality. CPTP was field tested at Denver Center in 1997 [1] and Fort Worth Center in 1998 [2]. Both tests showed that the controllers' preferred use of the Trial Planner was to identify conflict-free direct

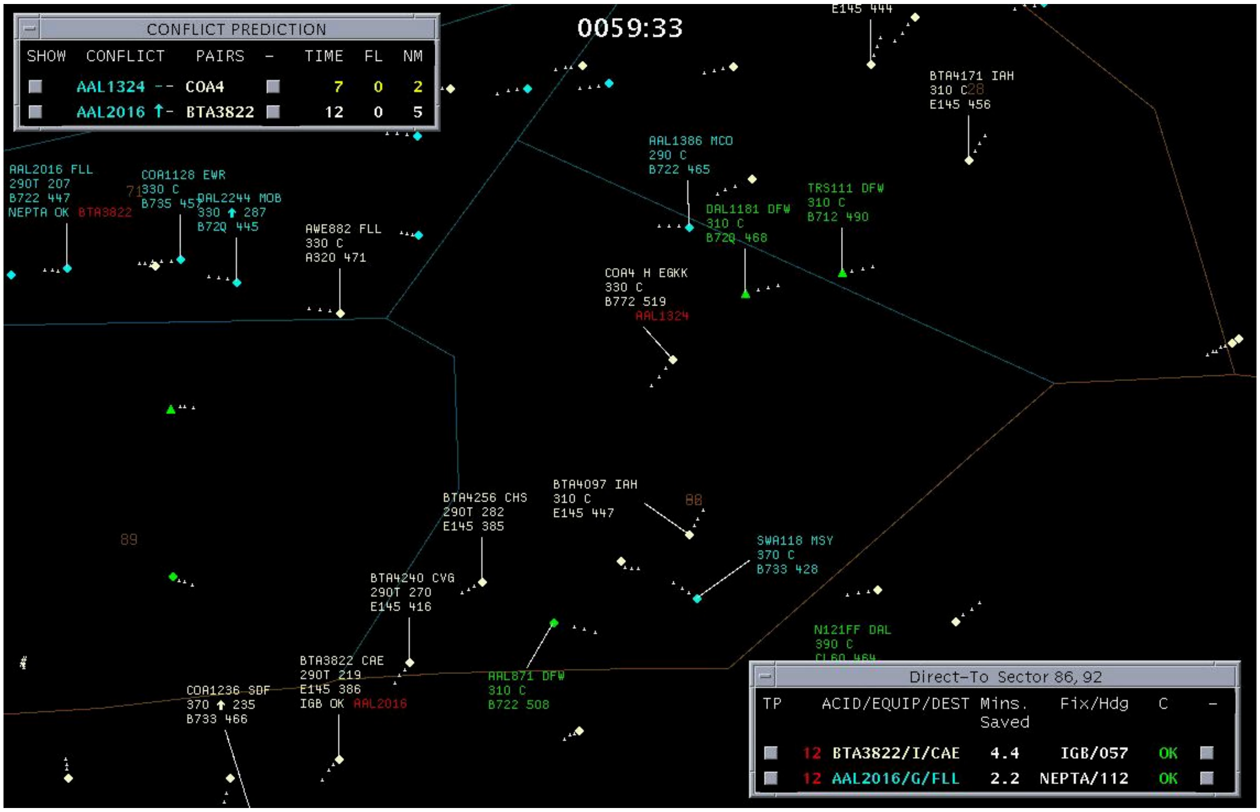

Fig. 1. Direct-To user interface

routes. A "direct-to" route advisory function was developed to automate the identification and evaluation of direct routing opportunities for en route Center controllers [3]. Direct-To and CPTP functionality are now fully integrated and we refer to this integrated capability as "Direct-To" or "D2."

The paper is organized as follows. The first section summarizes the functionality of the Direct-To Tool which is described in detail in References [1-7]. The next section describes functionality that was added in preparation for the field test including the capability to send a Host flight plan amendment using the Direct-To Trial Planner and the capability to analyze Host preferential routings. The third section describes the field test hardware and software architecture and the operational test procedures. The paper closes with an analysis of the test data and some conclusions.

Direct-To Tool

The CTAS route analysis and trajectory synthesis software computes 4-dimensional (x,y position, altitude, time) trajectory predictions in real-time for all aircraft, based on radar track and flight plan data from the Center Host computer, atmospheric data from the National Oceanic and Atmospheric Administration (NOAA) Rapid Update Cycle (RUC) forecast model, and aircraft performance models. All trajectory predictions are updated in response to each new radar track (every 12 sec), flight plan updates (when received), and atmospheric data updates (hourly). All aircraft trajectories are automatically analyzed for traffic conflicts and for time-saving direct routing opportunities. Updates are posted to the Direct-To user interface every 6 seconds.

The Direct-To user interface, including conflict probe and route advisory information and the trial planning functions, have been implemented as an integral part of a sector controller's traffic display. The user interface, shown in Fig. 1, includes aircraft targets, flight data blocks, sector boundaries and other features typically shown on a controller's traffic display. The Direct-To List (lower right) shows aircraft whose flight time would be decreased by 1 minute or more by flying direct to a downstream fix on their route of flight [3]. The Conflict List (upper left) shows traffic conflicts predicted to occur within the next 20 minutes [1, 2, 4]. Both lists can be hidden and may be placed anywhere on the traffic display by a mouse click-and-drag action.

Route advisory and conflict information are also displayed in the Flight Data Block. Figure 2 shows an example of a Flight Data Block with Direct-To route advisory and conflict probe information in the 4th line (the aircraft radar target and radar track histories are also shown). In this example, AAL2016 has a conflict with BTA3822 predicted along its flight plan route and a conflict-free direct route opportunity to NEPTA.

Fig. 2. Flight Data Block with direct route advisory and conflict information.

A mouse click on the conflict field (e.g. BTA3822 in Fig. 2) toggles a graphic display of the conflict information for AAL2016 and BTA3822. The conflict graphics, shown in Fig. 3, display the trajectories of both aircraft from current position to their first loss of separation point and any pertinent top-of-climb or top-of-descent points for transitioning aircraft. The conflict information display may also be toggled by clicking the associated entry in the Conflict List.

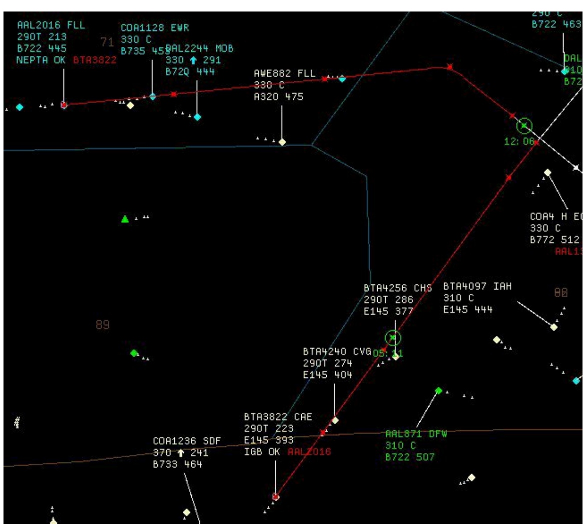

Fig. 3. Conflict information graphics.

A route trial plan is activated by clicking either the destination airport field in the Flight Data Block (e.g. FLL in Fig. 2), the direct route advisory in the Flight Data Block (e.g. NEPTA OK in Fig. 2), or the direct route advisory in the D2 List. A mouse click on the destination airport field activates a trial plan direct to the next fix along the route; the controller then selects the desired direct route fix by a mouse click in the Trial Planner's fix menu (see Fig. 4). The resulting trial plan is direct to the selected fix with the rest of the route unchanged. A mouse click on either the D2 advisory in the Flight Data Block or the corresponding entry in the D2 List activates a trial plan direct to the advised D2 fix with the rest of the route unchanged. The only difference between clicking the route advisory (NEPTA) and clicking the destination airport field (FLL) is the default fix upon Trial Planner activation.

Figure 4 shows a portion of the user interface with an active route trial plan. As shown in the figure, the fix menu includes all fixes along the route of flight. The time savings (or deficit) associated with a direct route to each fix is also shown in the fix menu. Once the Trial Planner is activated, the controller may click a different fix from the fix menu at any time and the trial plan status information is updated every 1 second. Trial plan status information includes the graphic display, flying time savings (or deficit), traffic conflicts, preferential routing, and wind-corrected magnetic heading to the Direct-To fix. Special Use Airspace probing is currently in the Direct-To software, but was not tested during the field test.

Fig. 4. Active route trial plan.

An auxiliary waypoint function [1,2,7] allows controllers to trial plan a vector heading to an auxiliary waypoint followed by a direct route to the selected Direct-To fix. An auxiliary waypoint is added to a trial plan by clicking anywhere along the trial plan route and then dragging the auxiliary waypoint to the desired position. Direct-To computes and displays the wind-corrected magnetic heading to the auxiliary waypoint. The auxiliary waypoint is automatically accounted for when the trial plan status information is updated, and is automatically included in the flight plan amendment message described in the next section.

Host Flight Plan Amendment Function

A key feature that was added to the Direct-To Tool for the field test is the ability to send a Host flight plan amendment by clicking the "Accept" button on the Trial Planner panel (Fig. 4). A Direct-To route amendment simply requires 2-3 mouse clicks - one to activate the trial plan, one to possibly modify the Direct-To fix or add an auxiliary waypoint, and one to send a flight plan amendment! The current system requires anywhere from 8-25 keyboard entries and requires the controller to look away from the traffic display. Using Direct-To, a controller may input a flight plan amendment while keeping their attention focused on the traffic display. CTAS automatically forms a flight plan amendment message whenever the Trial Planner is activated. The amendment message immediately updates to reflect the user's manipulation of the trial plan parameters (e.g., changing the direct-to fix, adding or moving an auxiliary waypoint, etc.) and the current position of the aircraft.

In support of the Direct-To flight plan amendment function, the FAA modified a segment of Host software called the "320 Patch." Prior to the Direct-To modifications, the 320 Patch was configurable for 2-way communication between CTAS and Host for TMA meter messages, *or* between the User Request Evaluation Tool (URET) and Host for flight plan amendments. Six lines of code were modified so that the patch could support Direct-To flight plan amendments *and* TMA meter messages simultaneously. Simultaneous support of TMA meter messages and Direct-To flight plan amendments was a key program objective since Direct-To was to be tested by connecting the Direct-To software module to the daily use CTAS/TMA system at Fort Worth Center.

Preferential Routing Analysis

During simulation testing of Direct-To with the Host, it was noted that several Direct-To flight plan amendments for aircraft landing at major Houston Center airports (IAH, HOU, SAT, AUS) were automatically overridden by Host Preferential Route Processing [8]. In order to help organize traffic flow into busy airports, the Host automatically applies Air Traffic Control (ATC) preferred routes for some arrival aircraft. However, traffic conditions do not always require that aircraft fly the entire preferential route. Operationally, controllers decide when to allow a short-cut of a preferential route. But, if they do, controllers don't always send a corresponding flight plan amendment because they know that Host preferential routing logic will override the amendment. It was determined that the Direct-To Tool should indicate to the controller when a Direct-To amendment might be over-ridden.

The method used to determine when a Direct-To flight plan amendment will be over-ridden is based on knowledge of the Host preferential routing logic. The Host uses so-called "transition lines" and "transition fixes" to determine when to apply a reroute. "A-lines" are the subset of transition lines that help determine rerouting for arrivals and A-lines are generally associated with one or more airports. Usually the Host automatically reroutes an aircraft onto an ATC preferred arrival route if its current flight plan intersects an A-line for its arrival airport. The one exception is: if the flight plan is direct to a transition fix ("T-fix") that lies on the preferential arrival route, then the Host will not override the flight plan amendment. This logic was implemented in the Direct-To Tool and the necessary adaptation data were added to the 56-day CTAS adaptation updates. A plus sign (+) next to the Direct-To fix in the Direct-To List indicates when the flight plan amendment would trigger a Host reroute. When trial planning an aircraft that could be affected by preferential routing, a "t" appears next to any T-fix in the Trial Planner's fix menu. This allows the controller to see which Direct-To amendments would not trigger a Host reroute. The Trial Planner panel and the graphic display also include clear indications (or warnings) when input of the trial plan would trigger a Host reroute. As the controller manipulates an active trial plan, preferential routing status is updated every 1 second with other Trial Planner information.

Software and Hardware Architecture

All CTAS tools utilize common software for input data processing and 4D trajectory synthesis. Consequently, the Direct-To tool can be implemented by connecting a single additional software module to an existing CTAS Traffic Management Advisor (TMA) system. This software architecture approach should enable the FAA to leverage the TMA investment made under Free

Flight Phase 1 to significantly reduce Direct-To deployment and life-cycle costs.

CTAS TMA has been in operational daily use at Fort Worth Center since October 1996. An important objective of this field test was to demonstrate simultaneous use of TMA and Direct-To in an operational environment. In preparation for the field test, the Direct-To software module (Profile Selector Center or PFS_C) was merged into the operational CTAS TMA software and released for use at Fort Worth Center. Direct-To functionality testing was incorporated into NASA release software test procedures and FAA William J. Hughes Technical Center (WJHTC) test procedures that demonstrate non-interference with the Host. Direct-To functionality is now part of every CTAS release.

Figure 5 illustrates the combined TMA/D2 system used for this field test. The above-mentioned PFS_C software module is the computational engine for Direct-To. The Direct-To user interface is intended to be implemented directly on the Display System Replacement (DSR) R-side display. However, for the prototype system used in this field test, the D2 user interface has been implemented in the CTAS Planview Graphical User Interface (PGUI) module (i.e. the CTAS traffic display). As shown in Fig. 5, a CTAS PGUI module configured for Direct-To was deployed (on an auxiliary flat-panel displays) at each of the 3 test sectors.

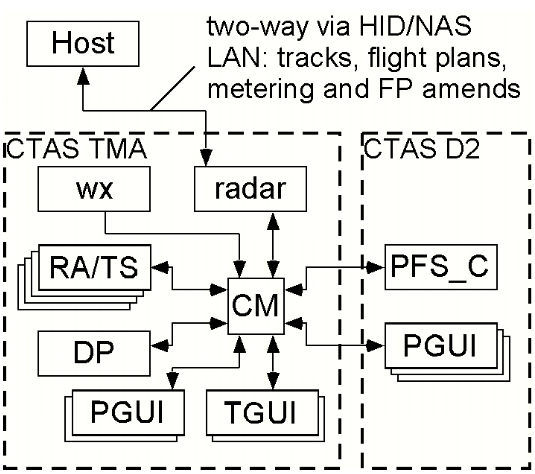

Fig. 5. CTAS TMA/D2 system

Field Test Operations

The operational field test evaluation of the Direct-To Tool was conducted at the FAA Fort Worth Center from May 21 – June 14, 2001. The objectives of the field test were: 1) evaluate Direct-To under operational conditions, 2) validate expected benefits to controllers and airspace users, 3) validate the integrated CTAS TMA/Direct-To/Host system, 4) identify modifications, improvements, and operational issues, and 5) gather data to refine the concept of use for D2 on the Display System Replacement (DSR).

Three high altitude sectors were selected for the test: Ardmore High (Sector 48), Texarkana High (Sector 90), and Paxto (Sector 86). Sector selection was based on the potential for direct route flying time savings, the variety of direct routings (e.g., departures, over-flights, aircraft on preferential routes), and traffic complexity. The goal was to test the tool under a variety of traffic conditions and a high level of traffic complexity. The Paxto sector, with its large number of transitioning and over-flight traffic, is considered to be one of the most complex sectors in Fort Worth Center.

The Direct-To user interface was displayed on 15 inch flat panel auxiliary display monitors installed at the D-Side position of each test sector. Figure 6 shows the flat panel installation at Ardmore High. Direct-To functionality is intended for the R-Side DSR display. However, for this prototype proof-of-concept field test, the only location deemed suitable for the auxiliary displays was the D-Side DSR console. The flat panel monitors were installed on articulating arms so the controllers could easily adjust the orientation of the monitor during test operations and stow the monitor during non-test periods.

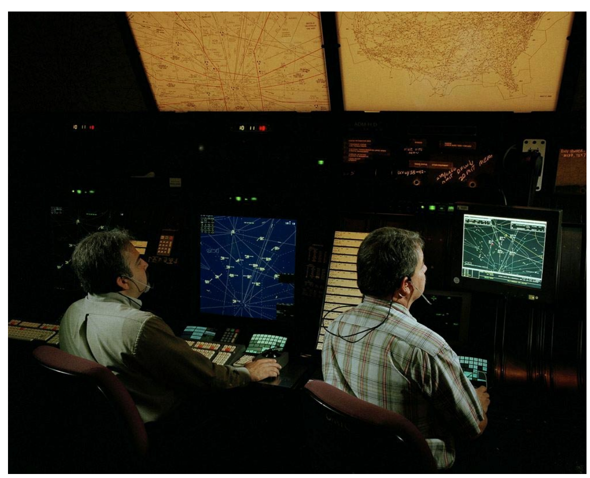

Fig. 6. Fort Worth Center sector with Direct-To auxiliary display.

A team of 9 full performance level controllers participated in the field test. None of the members of the controller team had prior experience with Direct-To or CPTP. Training included 4 hours of briefings and 17 hours of hands-on training using live and recorded data in a laboratory environment away from the operational floor. It should be noted that 20 hours of hands-on training were planned. But after 14 hands-on hours the team felt they had mastered the tool and needed no further training. Nevertheless, 17 hands-on hours were conducted to ensure the team was as proficient as possible before using the tool under operational conditions.

Field test operations were conducted during two 1.5 hour test runs per day on Monday – Thursday of each week. A total of 136 sector-hours of testing were conducted in 31 separate test runs over 4 weeks. Controllers activated 3204 trial plans and sent 1198 Direct-To flight plan amendments to the Host. The daily test schedule (Central Daylight Time), which covered a variety of traffic conditions from light to heavy, was:

Monday 2:00- 3:30pm, 5:45-7:15pm
Tuesday 12:00-1:30pm, 3:45-5:15pm
Wed/Thurs 7:00-8:30am, 10:45am-12:15 pm.

Both R-Side and D-Side positions of each sector were staffed with D2-trained controllers during all field test operations. Just prior to the start of each run, the D2 controllers checked onto the R-Side and D-Side positions of each sector. The tool was tested at all 3 sectors simultaneously. A NASA observer at each test sector recorded controller comments and sector activity and noted any relevant problems or operational issues. The observer wore a head set to monitor controller/pilot radio communication. Each test period was preceded by a 15 minute briefing and followed by a 1 hour debriefing.

Data recorded during the field test included radar track and flight plan data from the Center Host computer, RUC atmospheric data, all conflict predictions and Direct-To route advisories that were posted to the user interface during test runs, relevant parameters associated with every activation of the Trial Planner (e.g., direct-to fix, flight plan route and conflict status, direct-to route and conflict status, etc,), Enhanced Traffic Management System (ETMS) radar track and flight plan data (for analysis of aircraft track position after departing Fort Worth Center airspace), and Next Generation Radar (NEXRAD) severe weather data. Baseline ETMS track and flight plan data were obtained from archive for the 1 month period preceding the field test to be used for comparison of field test vs. baseline operations. Human factors workload and usability data were also collected during the field test. These data include workload questionnaires, recorded debrief interview sessions, and usability and interface evaluation questionnaires.

Test Data Analysis

This section covers controller feedback from questionnaires and debrief sessions, controllers' use of the Trial Planner and the Direct-To route advisories, flying time savings during periods of severe weather, and an analysis of net flying time savings while controllers were using Direct-To compared to baseline periods without Direct-To.

Controller Feedback

A modified NASA Task Load Index (TLX) questionnaire was used to measure the controller workload associated with the Direct-To Tool [9, 10]. Figure 7 shows the mean and standard deviation (error bars) of the TLX workload questionnaire responses. Both the R-Side and D-Side test controllers completed the questionnaire after each test run. A total of 187 samples were collected. On a scale of 1-10 (low-high), the responses for Tool Support and Satisfaction vs. Frustration with the tool are rated 7 or better, indicating D2 provided strong support with high satisfaction levels. The responses for Overall Effort and Time Pressure while using the tool are rated 4 or below, indicating the tool required low overall effort with little added time pressure. Responses for Mental Demand stayed mid-range showing that D2 provided good support with a minimal amount of effort required. In Fig. 7, the Overall Effort, Time Pressure, and Mental Demand are that which controllers perceived while performing their normal duties while using the Direct-To Tool.

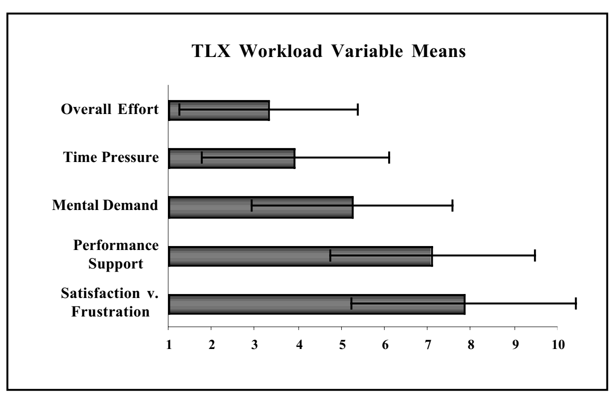

Fig. 7. Summary of TLX questionnaire feedback

A Usability and Interface Evaluation Questionnaire was given at the conclusion of the test to identify any design-related problems or issues and to allow the controllers to provide written feedback about the operational suitability of the Direct-To Tool. The questions were divided into various aspects of the tool; Direct-To List, Direct-To Graphics, Interactive Flight Data Blocks, Trial Planner Functionality. Most questions called for a numeric rating; some asked for a written response to specific questions. Figure 8 shows the mean and standard deviation (error bars) of the numeric controller responses. The results show that on a scale of 1-5 (bad to good) controller feedback on all tool functionality and ease of use was 4 or better. This further validates the basic tool design and its usefulness to controllers.

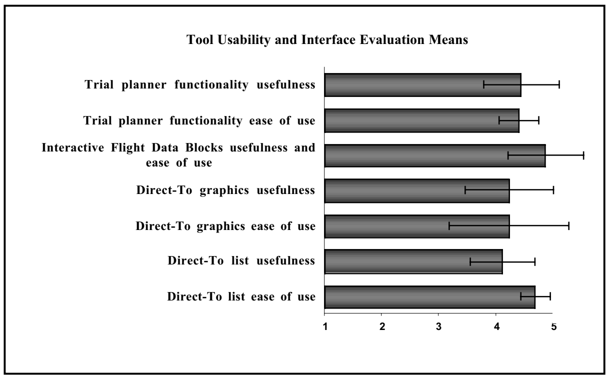

Fig. 8. Summary of usability and interface evaluation questionnaire feedback

Controller commentary regarding the Direct-To tool was consistently very positive. During one of the debrief sessions early in the testing the controller team was informally asked: "What part of the Direct-To functionality do you think would be beneficial if integrated into your R-Side traffic situation display?" A unanimous team response was: "All of it." One of the questions on the Usability and Interface Evaluation Questionnaire was: "If the Direct-To Tool was to be integrated as an R-Side tool what subset of functionality would you want to include?" The following is a representative set of written responses to this question:

"All of it was useful." "All of it. This *is* an R-Side Tool."

"All of it! Change [question] to read '*When* Direct-To Tool is integrated as an R-Side Tool.' "

"Ability to interact with data block. It's quick, efficient, and easy."

"I would want all aspects of the interactive data block maintained."

"Auxiliary waypoints, trial planning, conflict probe."

"Ability to amend flight plans from R-Side, conflict probe, makes it easy for R-Side to remain focused on traffic."

"I like all the functionality, but work on eliminating advisory boxes, condense information to data blocks only."

"All the data presented is important. Would like the ability to change size of box [D2 list]. Don't want MDM [R-Side traffic display] cluttered with boxes."

"Don't need the [D2] list if advisory will come up on data block."

"Get rid of box [D2 list] and operate from data block only."

Furthermore, the human factors workload data and usability data presented in Figs. 7 and 8 demonstrate that controller benefits were obtained by using the Direct-To Tool with little impact to reported controller workload. Both written and verbal debrief comments, as well analysis of data from a relative task workload questionnaire [11], help support these conclusions. Also, the test controllers reported extremely high levels of acceptance and pertinent application of Direct-To with their everyday operations. One controller said, "Controllers are very resistant to change and new ideas. I was really surprised at how all nine of us, real quick, after only a couple of days on the floor said this (Direct-To) is workable. Give us more!" Another said, "We see a lot of potential benefit from this tool. We've become more efficient, most definitely." Another said, "My perception of how busy I was went way up when the D2 Tool was turned off."

The National Air Traffic Controllers Association (NATCA) has no position on Direct-To as of now, but will be looking at it from the national level soon.

Trial Planner Activity

It was clear during the field test that controllers used the Direct-To Tool to investigate direct routes for those aircraft with D2 route advisories, and to evaluate routes for many other aircraft that did not have D2 advisories. Controllers used Direct-To to help evaluate and resolve conflicts, to evaluate and execute routing options, and to send flight plan amendments to the Host.

During the 31 test periods over four weeks, controllers in the Ardmore, Texarkana, and Paxto sectors used Direct-To to create a total of 3204 trial plans for 1937 different aircraft. Of the trial plans, 1198 were accepted (D2 flight-plan amendment sent to Host); the rest were rejected (cancelled without Host amendment). On average, one trial plan was created every 2.5 minutes, and one Direct-To Host amendment sent every 7 minutes. Figure 9 summarizes overall week-by-week trial-plan activity, where it is seen that, after the first week, controllers accepted (sent flight plan amendments to the Host) for about 40% of all trial plans.

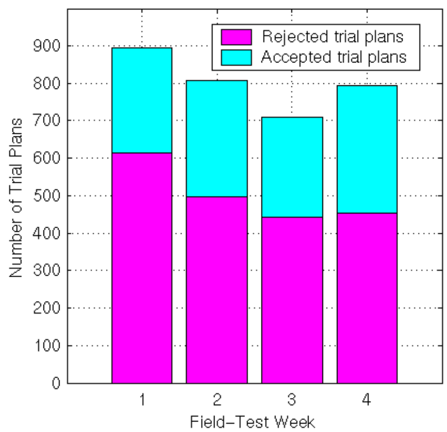

Fig. 9. Overall Trial Planner activity.

Trial plans were rejected perhaps because existing conflicts were not resolved or new ones were created. However, after the first week of testing only 11% of rejected trial plans had unresolved conflicts. This finding supports the notion that the tool was often used to simply enhance situational awareness.

It should also be noted that 10.5% (126 out of 1198) of Direct-To flight plan amendments included auxiliary waypoints. Controller feedback on the auxiliary waypoint function was very positive.

Direct-To Route Advisory Activity

During the test periods for the participating sectors, there were a total of 1117 aircraft that qualified for Direct-To route advisories (time saving ≥ 1 min). Controllers selected 602 of those aircraft for trial planning. Figure 10 shows the Direct-To advisory activity. An average of about 31% of all trial plans had D2 route advisories. It is interesting to note that after the first week, controllers accepted 50% of trial plans for aircraft that had Direct-To advisories, while accepting only 35% of trial plans for aircraft without D2 advisories.

As discussed earlier, Direct-To route advisories are displayed in the D2 List and in the Flight Data Block. A controller may activate a trial plan for a route advisory by clicking either the D2 List or the Flight Data Block. It was observed that after the first week most controllers preferred to operate without the Direct-To list displayed. The team commented that Direct-To route advisories in the Flight Data Block were adequate. Furthermore, since advisories were available in the Flight Data Block, the list could be hidden to reduce clutter on the traffic display. Figure 11 shows that, after the first week, only about 8% of trial plans were initiated from the Direct-To List. This clearly demonstrates controller preference for initiating a trial plan from the Flight Data Block and correlates with controller comments presented in the previous section.

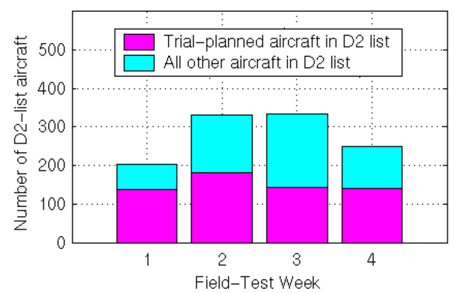

Fig. 10. Overall Direct-To Advisory Activity.

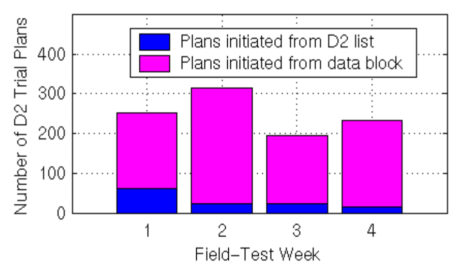

Fig. 11. D2 activation from list and data block

Tool Usage vs. Traffic Count

It was observed that controllers used the Direct-To Tool nearly continuously during testing even during periods of moderate to heavy traffic. Figure 12 shows time histories of aircraft count, D2 route advisories, and Trial Planner activity for a representative test period (Texarkana, Sector 90) with nominal traffic (Fig. 12a) and a test period when the sector (Paxto, Sector 86) was in Monitor Alert status (23:44 to 00:03). A sector is said to be in Monitor Alert status when the traffic count exceeds a certain threshold value. The Monitor Alert threshold for Sector 86 is 13 aircraft. Trial Planner activity is indicated at the bottom of the plot. An "A" indicates a trial plan that resulted in a D2 flight plan amendment. An "A*" is an amendment that resulted from a D2 route advisory. Trial plans without an "A" (or A*) were canceled without a Host amendment. A "D" indicates points at which a new D2 route advisory was posted to the display. Trial Planner activity in Fig. 12 clearly shows the controller using the tool while the sector was in Monitor Alert status. This suggests that the benefit-to-workload ratio of the Direct-To Tool, even in this experimental configuration (auxiliary displays), is high enough for controllers to use the tool during heavy traffic periods.

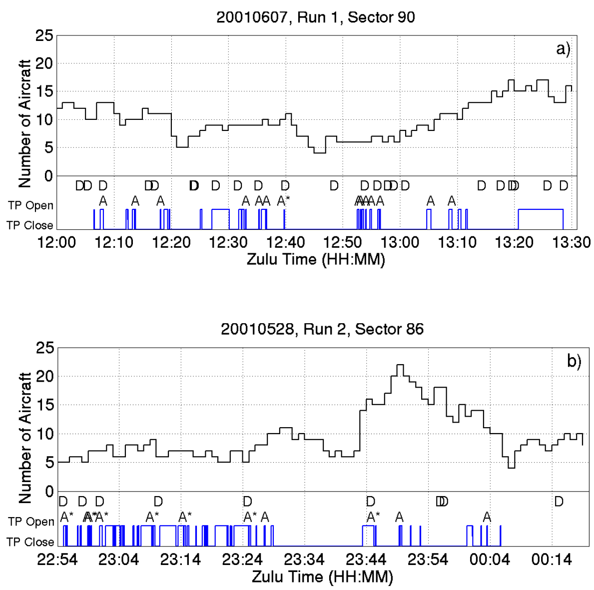

Fig. 12. Traffic count and D2 usage during (a) nominal and (b) Monitor Alert periods.

In order to characterize controllers' use of the Direct-To tool over all field test runs, all data were divided into successive 10 minute intervals. Fig. 13 shows a plot of the total number of Trial Planner actions vs. the average number of aircraft in the sector for every 10 minute interval in the field test. While the tool was operated in three sectors simultaneously, the data for each sector is a unique 10 minute interval. The bolded points are those for which the sector was in Monitor Alert status at some time during the 10 minute interval. The data show that Trial Planner usage varied widely across different traffic loads. In fact, the controllers activated the Trial Planner up to 13 times in intervals when the sector was in Monitor Alert status. These data clearly document controllers' use of the Trial Planner during a wide variety of traffic levels including Monitor Alert periods. Furthermore, the data suggest that the added workload was so low that controllers could use the tool even during the busiest periods.

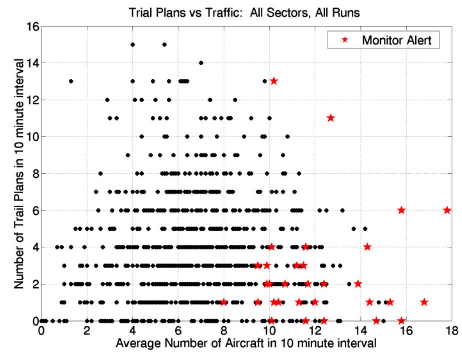

Fig. 13. Trial Planner use vs. traffic count.

Flying Time Savings for Weather Avoidance Routes

Severe weather in and around Fort Worth Center resulted in the implementation of weather avoidance routes for some aircraft during 8 of the 16 field test days. Weather avoidance routes typically include large deviations from a nominal flight plan to avoid regions of severe weather. However, severe weather regions may either move or dissipate before a weather avoidance route is updated, resulting in unnecessary rerouting.

The Direct-To route advisories brought to controllers' attention several workable direct routes, with savings on the order of 10 minutes, for aircraft flying obsolete weather avoidance routes. Using the Trial Planner's graphic display plus a graphic display of Next Generation Radar (NEXRAD) severe weather data, viewable from the sectors, the controllers could easily determine if a Direct-To route would put the aircraft through or near a region of severe weather. The controller team also pointed out that had the Direct-To advisory not been displayed, the direct routing opportunity for these obsolete weather avoidance routes may have gone unnoticed. These unusually long weather avoidance routes are often truncated when printed on paper flight strips. Consequently the controller might not notice a large deviation in the route, especially when glancing over a full bay of strips. Since the Direct-To Tool continuously displays direct routing opportunities that can save 1 minute or more, the route advisory triggers the controller's attention to evaluate the route with respect to weather and other factors.

Flight plan, radar track (Host and ETMS), and NEXRAD data for those aircraft that received a Direct-To flight plan amendment with a savings of 5 minutes or more were analyzed to identify those that resulted from weather avoidance routes. The analysis revealed that 27 aircraft appeared to be on obsolete weather avoidance routes prior to receiving the Direct-To flight plan amendment. Figure 14 shows a typical example of a Direct-To route amendment that resulted from analysis of a weather avoidance route that had not been updated. The figure shows the flight plan route prior to the D2 amendment, the D2 route, and the radar track position of the aircraft. The track data along the Direct-To route clearly show that the aircraft flew the Direct-To route and continued on course without deviation. The flying time savings was 10 minutes for this example. The total flying time savings for these 27 aircraft was 253 minutes with an average savings of 9.4 minutes.

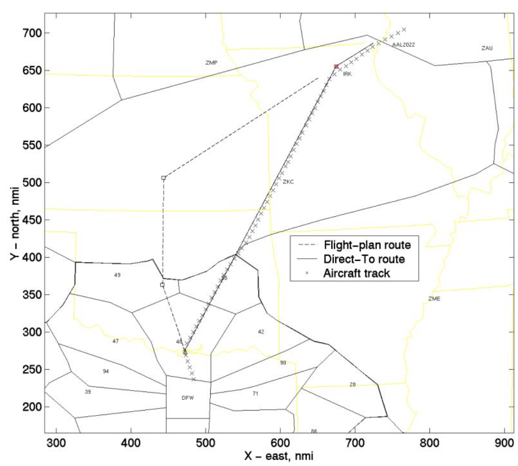

Fig. 14. Direct-To route resulting from analysis of weather avoidance route

An examination of Host and ETMS track data showed that 26 of the 27 aircraft flew direct to the Direct-To fix with either negligible deviation or a deviation for reasons other than weather (e.g., another downstream direct, traffic vector in a downstream Center).

All 405 flights that received Direct-To route amendments during the 8 severe weather days were examined to determine if any deviated due to severe weather. The analysis shows that severe weather could have been a factor in downstream deviations for 53 of these flights. However, the data clearly show that 40 out of 53 would have received the same deviation had they been on their original flight plan route. Therefore, only 13 of the 405 flights appeared to deviate back towards the original flight plan route.

The results show that less than 3% (13 out of 405) of aircraft possibly deviated off of the Direct-To route for severe weather avoidance and those deviations were relatively small. Nevertheless, the results illustrate the potential benefit of integrating severe weather data with the Direct-To Tool. Route advisories could be probed for severe weather penetration before posting to the display, and the Trial Planner could automatically probe for severe weather.

A small percentage of aircraft could encounter operational problems if they reach their destination on the order of 10 minutes early (too much fuel to land, no arrival gate, etc.). It is important to note, however, that flying time savings can usually be traded for fuel savings by reducing cruise speed.

Net Direct-To Flying Time Savings

One objective of the post test analysis is to compare direct route savings achieved during the field test, when controllers were using the Direct-To Tool, with baseline savings during periods when the tool was not in use. The goal is to estimate the net savings achieved with Direct-To in operation. Figure 15 illustrates the time savings analysis. Consider the notional route between

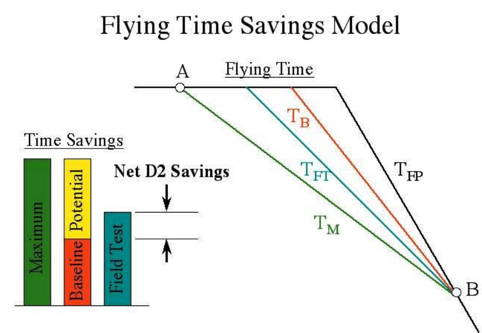

Fig. 15. Flying time savings model.

fix A and fix B where T_{FP} is the time to fly from A to B along the flight plan route and T_M is the minimum time to fly from A to B along the direct route. (Due to wind variations, the minimum time to fly is not always a direct route, but for the purposes of this baseline analysis, direct from A to B may be considered the minimum time to fly.) Since controllers give direct route short cuts under current operations, without Direct-To, T_B represents the average time to fly under current (baseline) operations. T_{FT} represents the time to fly when controllers were using the Direct-To Tool during the field test. As illustrated by the bar chart in Fig. 15, the additional Potential Savings (hereafter referred to as Potential Savings) is the maximum savings corrected for the savings achieved under current (baseline) procedures when controllers give direct routes without Direct-To aiding. If follows that the Net D2 Savings, or the saving over and above baseline, is that which may be attributed to controllers operating with the aid of the Direct-To Tool.

In the analysis that follows, track data recorded during field test operations are compared to baseline data retrieved for the 1 month period preceding the field test. The baseline data are for the same day of the week and the same time of day as field test data.

Specific routes were selected for the analysis by first determining the route/fix pairings with the largest number of Direct-To flight plan amendments during the field test. (A baseline analysis of every Direct-To route/fix combination is beyond the scope of this paper.) The results of a baseline analysis of the most common route/fix combinations should be representative of results for other routes with fewer Direct-To route amendments. Figure 16 shows the number of D2 amendments to various fixes for aircraft departing the Dallas/Fort Worth International Airport (DFW) and flying East through Sector 86. Fifty percent of all D2 amendments along this route were direct to HRV. Amendment data for Sectors 48 and 90 exhibit similar trends with 17% of Sector 48 amendments direct to LAA and 37% of Sector 90 amendments direct to PXV.

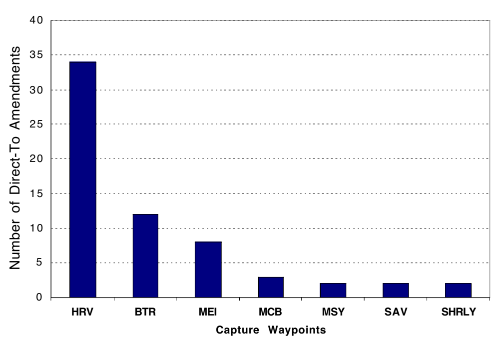

Fig. 16. D2 amendments for Sector 86 DFW departures.

Individual flights were then selected because the same flight generally flies the same route at the same time of day allowing field test and baseline data to be compared more directly. Flights were selected based on two factors. First, the data for the flight must include 4 or more field test samples where a D2 amendment was sent to the Host and 4 or more baseline samples. Secondly, in order to minimize variations due to factors such as weather diversions or additional direct routings in a downstream Center, the sample flights must have flown within 10 miles of initial and final reference fixes along the route. The initial reference fix (point A in Fig. 15) was chosen as the point where control responsibility usually transfers to the sector. The final reference fix (point B in Fig. 15) is the Direct-To fix for the selected route. Figure 17 shows the radar track position for one flight (AAL1614) through Sector 86 on 12 different field test and baseline days. The solid (blue) lines are field test days where a D2 amendment was issued, and the dashed (red) lines are baseline days. Figure 18 shows similar results for a flight (DAL204) through Sector 90 with direct routes to PXV.

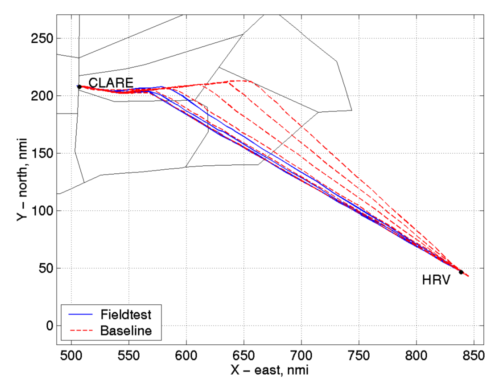

Fig 17. Field test and baseline tracks for AAL1614.

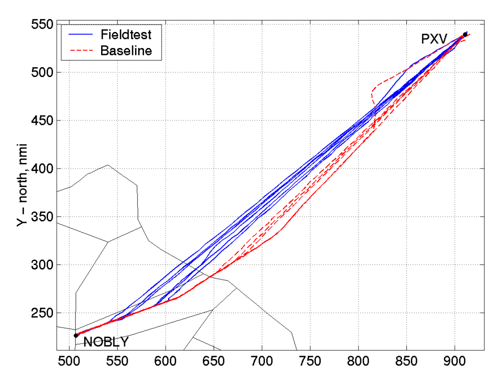

Fig. 18. Field test and baseline tracks for DAL204.

The flight path distance between the reference fixes for each flight was calculated using the radar track data. Table 1 shows the average flight path distance for flights that received D2 amendments during the field test and for the baseline flights. Table 1 also shows the average difference in path distance (field test - baseline) and the average difference in flying time. A nominal speed of Mach 0.8 at FL330 (465 knots ground speed) was used to calculate the time savings. The actual flying times could not be used for the comparison because of wind variation across the different sample days. The average flying time difference is the Net D2 Time Savings (see Fig. 15). The results show an average Net D2 Savings of about 1 minute while controllers were using the Direct-To Tool compared to baseline (no-tool) days.

	No. of Sample Flights	Avg. Path Dist. (nmi)	Δ Dist. from Baseline (nmi)	Avg. Net D2 Time Savings (min)
AAL1614				
Field Test	4	375.65	-8.04	1.04
Baseline	6	383.69	--	--
DAL204				
Field Test	6	515.90	-7.43	0.96
Baseline	5	523.33	--	--

Table 1. Net D2 Time Savings - common route, common flights.

The Net D2 Time Savings analysis was repeated using a larger sample of flights on the same two routes (Sector 86/HRV, and Sector 90/PXV). In this analysis the requirement for 4 field test and 4 baseline samples of each flight was relaxed. Also, the flights are at different times of the day so the flights were effected by different operational factors. The results, shown in Table 2, indicate a positive, but slightly lower Net D2 Savings than that shown in Table 1.

	No. of Sample Flights	Avg. Path Dist. (nmi)	Δ Dist. from Baseline (nmi)	Avg. Net D2 Time Savings (min)
All 86/HRV				
Field Test	18	377.13	-5.88	0.76
Baseline	27	383.01	--	--
All 90/PXV				
Field Test	25	517.05	-3.40	0.44
Baseline	51	520.45	--	--

Table 2. Net D2 Time Savings – common route, multiple flights.

Referring to Fig. 15, the Net D2 Savings expressed as a percentage of Potential Savings is the portion of Potential Savings that was achieved while controllers were using Direct-To under operational conditions. This percentage is defined as S, the Normalized Net D2 Savings, where S is expressed as:

$$S = (TB - TFT)/(TB - TM).$$

Table 3 shows the Normalized Net D2 Savings for the common route, common flights analysis (AAL1614, DAL204) and for the common route, multiple flights analyses (All 86/HRV, All 90/PXV) described above.

	Number of Flights		Normalized
	Field Test	Baseline	Net D2 Savings
AAL1614	4	6	66%
DAL204	6	5	59%
All 86/HRV	18	27	51%
All 90/PXV	25	51	35%

Table 3. Normalized Net D2 Savings

The normalized savings in Table 3 may be used to estimate the actual savings that could be achieved if Direct-To were in operation throughout Fort Worth Center. Through laboratory analysis of Fort Worth Center traffic, the Potential Savings at Fort Worth Center has been estimated at 1,800 flying minutes per day or about $18,000,000 per year [3]. It is important to note that these savings estimates from Reference [3] are corrected for direct routes issued by controllers (without D2) and are therefore consistent with the definition of Potential Savings illustrated in Fig. 15. Based on the D2 savings model described above, the estimated actual savings is the Potential Savings scaled by the Normalized Net D2 Savings. However, certain factors must be considered when using field test data (Table 3) to scale the laboratory-derived savings estimates [3]. It is assumed that the normalized savings in Table 3 are representative of the savings that could be achieved had Direct-To been tested throughout Fort Worth Center. Procedures in low altitude sectors and DFW arrival sectors, which were not included in the field test, could produce different results. There are more special airspace regions below FL240 than there are above FL240. This could lead to reduced savings in low altitude sectors. Savings for DFW arrival aircraft are not included in the Potential Savings figures [3]. And inclusion of DFW arrivals could yield additional savings. Furthermore, the Potential Savings estimates were computed on days when severe weather did not impact aircraft routing. As described above, the results of this test clearly show that Direct-To provides a relatively large additional benefit during periods of severe weather where aircraft may be flying obsolete severe weather avoidance routes. The average D2 savings during nominal weather conditions (no severe weather) was 2.3 minutes per D2 advisory [3]. As shown above, the average actual savings during severe weather periods was 9.4 minutes per D2 route. Given the results in Table 3, and the aforementioned technical and operational factors, a Normalized Net D2 Savings of 50% is a reasonable estimate. A 50% scale factor equates to 900 minutes of net flying time savings per day or $9,000,000 annual savings at Fort Worth Center alone.

Additional Observations

Controllers developed confidence in the Direct-To trajectory analysis, particularly the conflict probe information and the top-of-climb predictions. An aircraft's top-of-climb is an important consideration when controllers evaluate conflicts and routing options in transition airspace. For any conflict probe tool to be effective it is important that controllers have confidence in the trajectory predictions.

On at least occasion during the field test a pilot asked one of the D2 controllers for a direct route. Upon trial planning the direct route, the controller noted the direct route would have resulted in increased flying time due to wind effects. When the controller relayed that information to the pilot, the pilot retracted the request. This case highlights the importance of the flying time analysis being available whenever the controller activates the Trial Planner.

During the first week of testing, Fort Worth Center operations received a call from Memphis Center requesting that certain direct routes (e.g. direct EOS) from Ardmore to fixes in Kansas City Center not be issued. The request was certainly honored. The routing in question would route aircraft into Memphis Center airspace for a very short period of time (about 5 min) before entering Kansas City Center. (In Fig. 14, the Direct-To route from Ardmore passes just West of the small segment of Memphis Center airspace at the point where the route exits Fort Worth Center.) The routing is undesirable since Memphis Center must take control of the aircraft and then almost immediately transfer control to Kansas City Center.

Also during the first week of testing, some East-North-East-bound Direct-To routes issued in Ardmore routed aircraft through a Fort Worth Center sector (Decod, Sector 42) which primarily handles DFW arrival traffic. The Decod controllers asked that the Direct-To controllers not send aircraft on direct routes through the Decod sector. This request was also honored. The Decod controllers were concerned that a Direct-To aircraft might conflict with West-bound DFW arrivals that were not under Fort Worth Center radar coverage at the time the Direct-To route was issued. It should be clear however, that radar coverage extends well beyond the Center boundary (about 45 miles East into Memphis Center airspace in this example) and Direct-To starts computing a trajectory for conflict probing as soon as the first radar track is received. Also, this would not be an issue if CTAS were operating in the neighboring Center and data were exchanged for conflict probing. It should also be noted that Direct-To routes from Sector 90 through Sector 42 were generally not an issue.

Conclusions

The field test thoroughly exercised Direct-To functionality under operational conditions. Controllers activated 3204 trial plans and sent 1198 Direct-To flight plan amendments to the Host during 136 sector-hours of operational testing.

Controller acceptance of the Direct-To Tool was very high. Controller commentary and written feedback suggest that significant controller benefit could be achieved if Direct-To functionality were integrated with the R-Side traffic situation display.

The results document consistent levels of Direct-To usage during all traffic conditions and that added workload associated with Direct-To is low enabling controllers to use the tool even during busy traffic periods.

The Direct-To Tool provides a means of dynamically identifying and updating obsolete weather avoidance routes. An average savings of 9.4 minutes per flight was realized for 27 aircraft that were on obsolete weather avoidance routes prior to receiving a Direct-To flight plan amendment.

A methodology was presented to estimate the net flying time savings achieved while controllers were using Direct-To compared to baseline (no-tool) operations. The test data show an average net savings of about 1 minute per flight.

The test data suggest that about 50% of laboratory-derived estimates of flying time savings could be achieved if Direct-To were in operation throughout Fort Worth Center. This equates to a savings of 900 flying minutes per day or $9,000,000 per year.

Controllers developed confidence in the Direct-To trajectory analysis, particularly its conflict probe information and its top-of-climb predictions.

The operation of TMA and D2 on a common CTAS system was validated under operational conditions. There was no adverse impact to TMA during 136 sector-hours of simultaneous TMA/D2 operations.

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